LIST OF SYMBOLES:

Symbol	Title
LL	Liquid limit
PL	Plastic limit
PI	Plasticity index
ρ_t	serviceability index
CBR	California bearing ratio
ESAL	Equivalent single axle load

1.INTRODUCTION

1.1 Flexible and rigid pavements

The structural layers of road or airfield pavement are required to serve two main functions, firstly, to distribute traffic loads to an extent that the sub-grade is not deformed beyond acceptable limits within the working life of the pavement. Secondly, to protect the underlying soil or sub-grade from damage by water or frost. There are two recognized form of pavement structure, which function in entirely different ways. There are known as a flexible and rigid pavements (F.G. Bell (1975)).

Traditionally the main part of a flexible pavement was a layer of material which has no tensile strength, load distribution arising through the internal friction or natural shear strength of the material, in the manner illustrated in figure 1, pavement structures formed in this way do not prevent moisture percolating to the sub-grade and do not provide sufficient abrasion resistance to prevent surface damage by traffic. Bituminious surfacing are used on flexible pavements to provide both wearing surface resistance to damage by vehicles and a waterproof layer to minimize water penetration into the sub-grade. The material used in flexible pavements has traditionally been selected graded stone be compacted by rolling and sometimes vibration. Due to difficulties in obtaining suitable stone, and problems arising from the very high imposed loads on major roads and airfield. This form of construction is becoming less popular, preference being given to stabilizing the base layers with bituminous or cement binder. Rigid pavements of which concrete is the only practical example, have considerable tensile strength and distribute traffic loads by acting as a stiff plate as illustrated in figure 2. To minimize high local stresses, a concrete slab requires uniform support, it is also sometimes necessary to provide a working platform on which to build the concrete. For these reasons a sub-base is often laid beneath a concrete pavement (F.G. Bell, 1975).

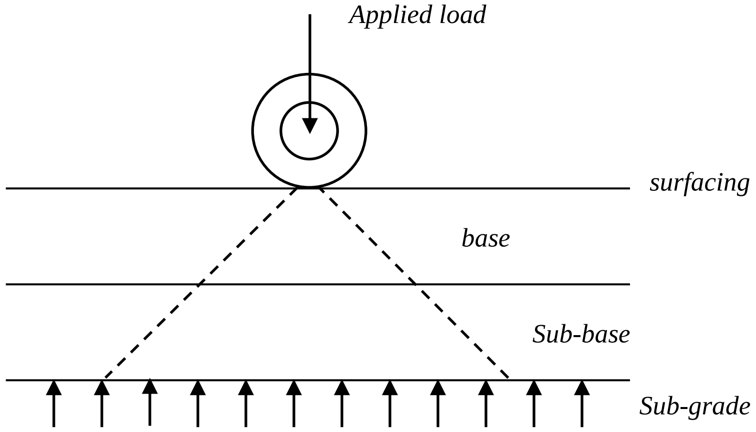

Fig.1. Load distribution through a flexible pavement. (F.G. Bell, 1975)

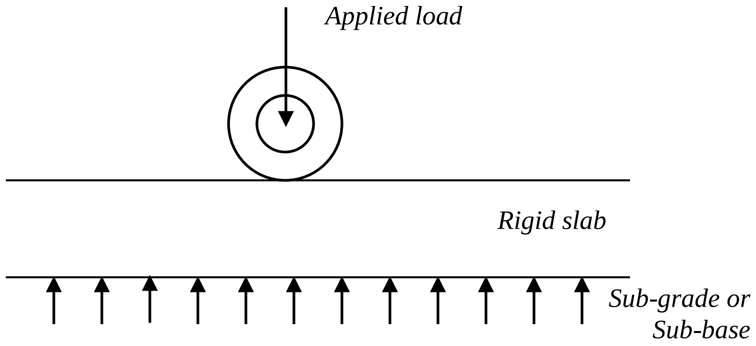

Fig.2. Load distribution through a rigid pavement. (F.G. Bell, 1975)

Although the final functions of the sub-base layer in the two forms of pavement are different, contractors are finding that improvement of the natural stability of the sub-base materials is desirable to permit the paving plant, building the upper layers, to operate with greater efficiency and to minimize delays due to inclement weather.

Although cement-stabilized materials have tensile strength, they are normally defined as a flexible. The tensile strength would improve the load-spreading characteristics of cement-stabilized materials compared with unbound materials, it is doubtful if advantage could be taken of this strength in the long term because of the development of shrinkage cracks, which may increased by traffic.

1.2 Sub-base material classification

The sub-base material must be classified according to the (AASHTO) requirements depending upon the construction requirements for roads in Iraq. Table 1 shows the classification of AASHTO for sub-base material. in order to classify the sub-base material according to the (AASHTO) specifications, the sieve analysis must be attended.

Table 1. Classification of AASHTO

Gradation test	*% passing*			
Sieve size (mm)	*Class (A)*	*Class (B)*	*Class (C)*	*Class (D)*
75	*100*	*-*	*-*	*-*
50	*95-100*	*100*	*-*	*-*
25	*-*	*75-95*	*100*	*100*
9	*30-65*	*40-75*	*50-85*	*60-100*
4.75	*25-55*	*30-60*	*35-65*	*50-85*
2.36	*16-42*	*21-47*	*26-52*	*42-72*
0.3	*7-18*	*14-28*	*14-28*	*23-42*
0.075	*2-8*	*5-15*	*5-15*	*5-20*

Table 2 shows the chemical and physical properties of sub-base material used in roads and other construction works.

1.3 Liquid limit and Plasticity index Tests

Liquid limit(LL) is defined as the moisture content; in percent, required to close a distance of (12.7 mm) along the bottom of the groove after 25 blows in a standard liquid limit device.

Table 2. Chemical and physical properties

Property	*Test method*	*Specification*
Liquid limit %	*AASHTO T89*	*<25%*
Plasticity Index %	*AASHTO T90*	*<6%*
Organic materials %	*BS 1377.No.8*	*<2%*
So3 salts %	*BS 1377.No.9*	*<5%*
C.B.R %	*AASHTO T193*	*<35%*

Plastic limit(PL) is defined as the moisture content; in percent, at which the soil when rolled into threads of (3.2 mm) in diameter, crumbles.

Plasticity Index(PI) is the difference between the liquid limit and plastic limit of a soil.

1.4 California Bearing Ratio Test (CBR)

The laboratory CBR test is generally carried out on remolded samples of the sub-base material, and is described in BS 1377. The sample must be compacted to the expected field dry density at the appropriate water content. The appropriate water content is the in-situe value used for the field compaction (G. N. Smith,1998).

1.5 Organic content and So_3 content

The organic content test and So_3 content test were made in this study. These tests were illustrated in most of geotechnical references and laboratories manuals.

1.6 Cement requirements

Ordinary Portland cement (from Al-Kufa cement plant) are used in this work. Its chemical composition and physical properties are presented in Table 3.

2.THE LABORATORY TESTS

Many laboratory tests were made to the sub-base material which was taken from the Alromania company quarry in Al-Najaf sea region. Both tests without cement and with cement were made.

Table 3. Chemical composition and physical properties of Portland cement (According to Al-Najaf Laboratory Testing Report)

Chemical Compound	*Results %*	*Specifications %*
Cao	*61.47*	---
So_3	*2.29*	*≤ 2.8*
Mgo	*2.42*	*≤ 5*
Fe_2O_3	*3.32*	---
Sio_2	*21.1*	---
Al_2O_3	*6.14*	---
L.O.I	*1.86*	*≤ 4*
I.R	*0.53*	*≤ 1.5*
C_3A	*10.95*	---
Physical Properties	*Results*	*specifications*
Time of Setting *Initial setting, hr* *Final Setting, min*	 *1:44* *3:15*	 *≥ 45 min* *≤ 10 hr*
Compressive Strength, MPa *3 days* *7 days*	 *26.1* *34*	 *≥ 15* *≥ 23*

2.1 Tests without cement

2.1.1: Sub-base material classification:

Sieve analysis test: This test was made for a sample of material soil weighs 2000 gm after drying it in the oven to avoid the volume changes due to the moisture content, the set of sieves was used with openings (75 , 50 , 25 , 9 , 4.75 , 2.36 , 0.3 , 0.075)mm and pan in the lower of a set. The gradation of sub-base material of the mechanical sieving operation for a period of 10 minutes is shown in Table 4. Depending on the above specifications (AASHTO), ***the sub-base materials used can be classified as (Class B).***

Table 4. Gradation of sub-base material

Sieve size (mm)	*% passing*	*Class (B)limits*
75	*100*	*-*
50	*100*	*100*
25	*80*	*75-95*
9	*72*	*45-75*
4.75	*49*	*30-60*
2.36	*32*	*21-47*
0.3	*26*	*14-28*
0.075	*10*	*5-15*

2.1.2: Sub-base material requirements:

In order to use the granular material as a sub-base coarse layer in any construction work must be exist the requirements of the specifications of the region of work. In this research, the most important required available tests were made. Table 5 shows the tests made. The specimen of sub-base material which is used exists the requirements of the specifications required to construction works in Iraq. The optimum moisture content of the materials was found as (5% by weight of granular materials) according to AASHTO T180.

Table 5. Results of laboratory tests without cement

Property	*Test method*	*Results*	*Specification*
Liquid limit %	*AASHTO T89*	*23*	*<25%*
Plasticity Index %	*AASHTO T90*	*1.7*	*<6%*
Organic materials %	*BS 1377.No.8*	*1.5*	*<2%*
So3 salts %	*BS 1377.No.9*	*3.5*	*<5%*
C.B.R %	*AASHTO T193*	*35.2*	*>35%*

2.2 Tests for Specimens Mixed with cement

2.2.1: Influence of cement addition on Atterburge Limits:

Figure 4 shows the addition of cement on the Liquid limit of the mixture of soil –cement. This figure shows that the Liquid limit increase with the increment of cement content ratio.

Figure 5 shows the addition of cement on the Plasticity index of the mixture of soil–cement. This figure shows that the Plasticity index decrease with the increment of cement content ratio.

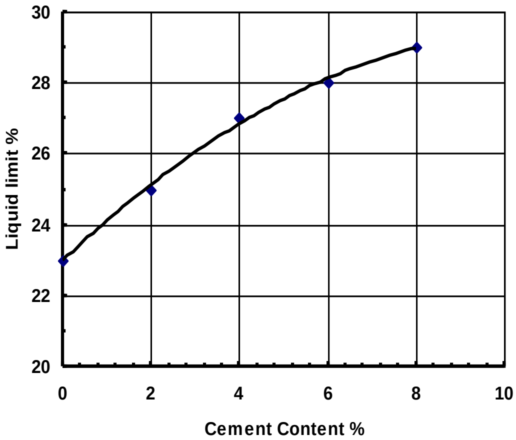

Fig.4. Effect of cement on Liquid limit

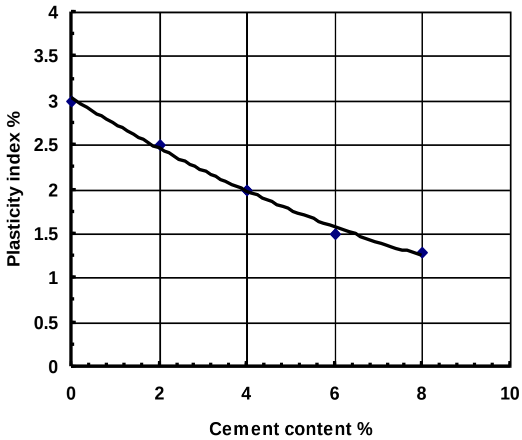

Fig.5. Effect of cement on Plasticity index

2.2.2: Influence of cement addition on CBR test results:

In order to certify the effect of cement addition on CBR test of soil cement mixtures, the following five percentages of cement (0, 2, 4, 6, and 8) percent by weight of granular material are taken. The percentage of water content has been used for each mix was taken as ***5%*** (that is obtained from optimum moisture content according to AASHTO T180).

Figure 6 shows the effect of addition of cement on the CBR values of the mixture of soil –cement. This figure shows that the CBR value increase with the increment of cement content ratio. The value of CBR has a good increment with the increment of cement content up to 6%, then the ideal addition percentage of cement addition as 6%.

The addition of 6% cement to the granular material gives CBR about 82%, the mixture with this CBR value can be used as base course layer (that is in several road projects designed with base course with CBR more than 80%) and this is may give an economical benefits if the specifications are applied in road works.

To certify the effect of aging on soil cement mixture, the following four aging time are used for mixture with 6% cement that are (0.5 hr, 24 hrs, 48 hrs, and 168 hrs), and the results shown in figure 7.

As shown in figure 7, as the time of the test specimen late can be gotten CBR value more than the value at first (after about 0.5 hr), that is because of the cement get a strength with time and the CBR value may increase about 2 times the value of CBR at first (about 82 %), this benefit is more adequate in the field. The curing process gives a strong course may be used as a base course not a sub-base course in local regions.

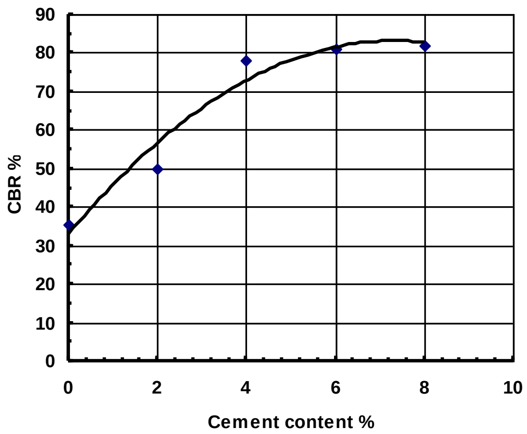

Fig.6. Effect of cement on CBR test results

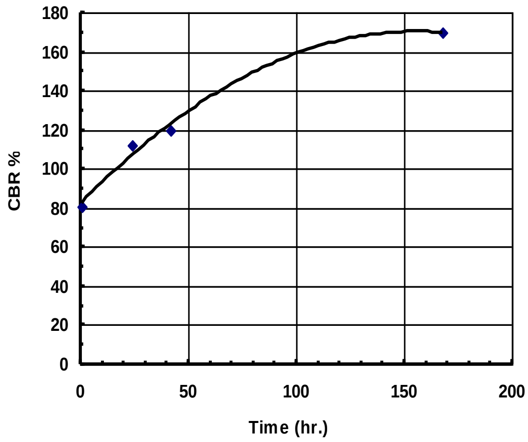

Fig.7. Effect of Aging on CBR test results

3.Influence of cement addition to granular materials on pavement structure layers due to traffic load:

In order to certify the effect of cement addition to granular materials used for sub-base course. Two cases of pavement structure were estimated as shown in figure (8), the necessary required information for study are given in this figure also.

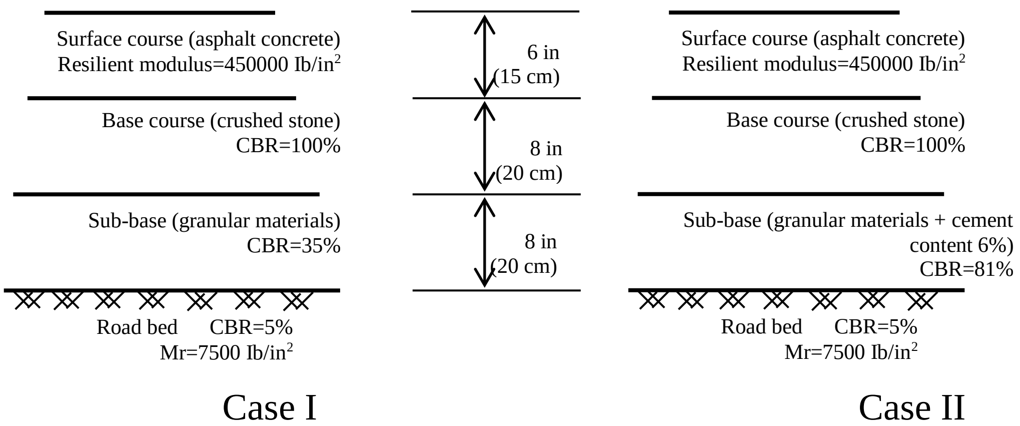

Fig. 8. The cases of pavement structure were estimated in this study

The 1993 AASHTO guide for design of flexible pavement used in this study to indicate the ESAL repetitions for case I (use granular material as sub-base course) and case II (use granular material with 6% cement as sub-base course) for an urban highway estimated that it takes about a week for water to be drained from within to pavement and the pavement structure will be expressed to moisture levels approaching saturation for 30 percent of the time, and the results shown in figure 9. As shown in figure (8), case I of pavement structure that is used granular materials as sub-base course carry 1.1×10^6 ESAL repetitions until reach terminal serviceability index ρ_t=2.5, but for case II which is used granular materials with 6% cement as sub-base course carry 1.6×10^6 repetitions of ESAL until reach terminal serviceability index ρ_t=2.5.

For these circumstances it is apparent that establish sub-base course from granular materials with 6% cement is effective in increasing ESAL repetitions by about 45% greater than sub-base course established from granular materials without cement only within the limitation of this study.

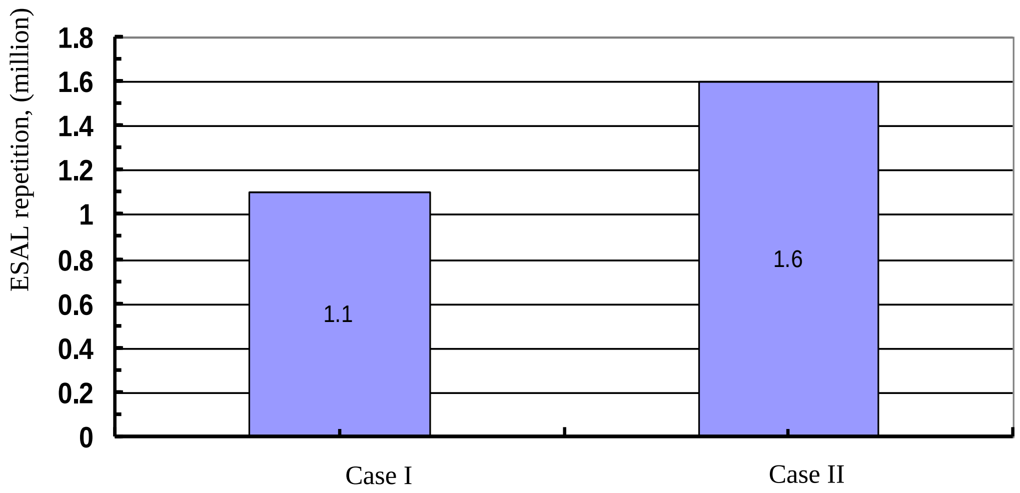

Fig. 9. ESAL repetitions for pavement structure layers (case I and caseII)

CONCLUSIONS

1- The addition of cement to the granular materials leads to increase Liquid Limit.
2- The addition of cement to the granular materials decrease the Plasticity Index.
3- The ideal percentage of cement which can be used is 6% .
4- CBR test results increase with increasing of cement content.
5- The addition of 6% cement to the granular materials increases CBR value with a percentage more than 100%.

6- The addition of 6% cement to the granular materials make the CBR value larger than 80%, this value able the designer use the mixture as base coarse.

7- The value of CBR increases with 170% after 7 days from the addition of water that is used to the hydration of cement.

8- The cement addition as 6% to the sub-base course increases ESAL repetitions by about 45% greater than sub-base course established from granular materials without cement until reach terminal serviceability ρ_t =2.5.

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المصادر باللغة العربية:

1- نمذجة المواد الإنشائية – المركز القومي للمختبرات الإنشائية.

2- مواصفات المواد الإنشائية - المركز القومي للمختبرات الإنشائية.